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## PRECIPITATION IN THE DRAINAGE AREA OF THE GREAT LAKES, 1875–1924

### WITH DISCUSSION OF THE LEVELS OF THE SEPARATE LAKES AND THEIR RELATION TO THE ANNUAL PRECIPITATION



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SYNOPSIS

Owing to extensive discussion of lake levels and the causes controlling them, the precipitation data of the Weather Bureau and the Canadian Meteorological Service for the drainage basin of the Great Lakes have been examined with care. From 1875 trustworthy determinations are possible. The precipitation averages about 32 inches per year, and in general increases from north to south. As a rule the stations considerably above the levels of the lake surfaces indicate more precipitation than those close to the lake levels. The lake surfaces probably receive about as great precipitation as do stations at or near the shore, the deficiency in catch in gages exposed on islands or peninsulas being considered as due to increased wind effect.

The precipitation was unusually heavy, on the average, from 1875 to 1885, and the period 1875 to 1899 shows more precipitation at almost every station than the period 1900 to 1924. However, there were groups of a few successive years with scanty precipitation before 1900, one, indeed, before 1890. From 1917 to the present nearly the whole area has had decidedly scanty precipitation. It is not believed that removal of the forest cover has materially affected the amount of water reaching the lakes.

The water levels seem to be closely related to the quantity of precipitation, delays of a year or more often appearing in the response of the levels, since the run-off is not immediate. It is highly improbable that the deficient falls of recent years indicate permanent or semi-permanent establishment of scanty supplies of precipitation. A return over several years to the normal quantity of precipitation or to even greater amount may be expected to end the present prevalence of unusually low levels in the lakes, just as various periods of low water during the nineteenth century were terminated by generous rainfall.

OUTLINE OF SUBJECTS



### PRECIPITATION DATA USED IN THIS INVESTIGATION

*Development of precipitation observations in the Great Lakes region.*—The official collection of daily weather statistics, including measured precipitation, in the United States for the purpose of issuing forecasts of probable weather conditions, began in the latter part of 1870, when steps were taken to secure reports from a group of stations as well distributed over the country as was then possible.

On account of the growing importance of the Great Lakes as commercial highways at that time, and the rapid development of important business centers along their shores, more stations per unit area were established in this region than in other parts of the country. It is therefore possible to secure a more accurate estimate of the distribution of precipitation in this region during the early years of the Government Weather Service than elsewhere.

At a few points in this region the Army Medical Corps was already taking weather observations, as were also individuals and important observatories in cooperation with the Smithsonian Institution at Washington.

About the same time meteorological observations were begun on a rather extensive scale in Canada, and a number of stations were established on the Canadian shores of the Great Lakes or within their drainage areas.

In subsequent years, more observing stations of the two Government weather services were established as needed for forecast work, and, in addition to these, an extensive system of cooperative weather stations was gradually built up, so that for many years the entire drainage area of the Great Lakes has been covered by such a network of stations that it is possible to determine closely the daily, monthly, seasonal, or yearly distribution of precipitation over all its parts.

*Length of record and distribution of stations.*—In making this study it appeared desirable that the period covered should be sufficiently long to embrace all probable phases of precipitation distribution, including even those frequently assumed to recur over well-defined short or moderately long periods. Moreover, a good distribution of stations was necessary in order that the separate lake basins and the drainage area, as a whole, should be represented. This, of course, was only possible by reducing all the records to a homogeneous system, each station to cover the entire period of years.

In examining the available data for the early years it soon became apparent that a period of heavy precipitation existed during those years over the Great Lakes, particularly during the 10-year period beginning about 1875. Although few stations were in operation during this period over much of the Superior basin, as well as over smaller areas in some others, it was clear that the period should be included in any discussion of the variations in precipitation from normal, even though extensive interpolations were necessary to determine the probable precipitation.

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In view of the above, it appeared best to limit the discussion to the 50-year period beginning 1875 and ending 1924, as this length of period would doubtless embrace the limits within which the precipitation might be expected to fluctuate, and would likewise disclose any tendencies toward the so-called recurring short-period cycles, should such exist. Also by 1875 the reporting stations had become sufficiently well distributed to make possible a reasonably correct estimate of the precipitation over areas not then fully represented, and from which actual data would soon become available. Brief notes of leading features of 1925 have been included since that year ended.

During the early years of the period the records, except those maintained for forecast purposes, were frequently broken. New stations were constantly being opened, however, so that moderately accurate charts of monthly and annual precipitation for the greater part of the region are available for all the years.

It was not possible to secure for the purposes of this study as good distribution of stations over the Lake Superior area as elsewhere. Moreover, it was desired that each station, even though its record was not continuous through the 50 years, should nevertheless represent a distinctive area, embracing frequently several stations with records for different periods, but so located as to justify the assumption that they represented the precipitation of the district. In such cases the name of the station having the longest record or most centrally located was adopted for the locality, to which was added the word "near," thus indicating that the record is a composite of records made at the central station and at near-by points. In cases of broken records at these stations, missing months or years were supplied by interpolation from the corresponding monthly or annual charts, or as described below.

In localities where the lack of stations in the early years precluded interpolation from the charts, a station with the longest record, usually from 30 to 40 years or more, and best located for the purpose, was selected to represent the region, and precipitation ratios were established between that and the nearest full-record stations. From these ratios, values for the earlier years at the short-record station were estimated, it being assumed that, on the average, the ratios existing between near-by stations over a considerable period will continue indefinitely. It was generally possible to secure ratios of a short-record station to two or occasionally three favorably located full-record stations, thereby insuring a reasonably accurate estimation.

With these estimated values, together with figures from the stations having complete records, it was possible to assemble data from nearly 100 points covering all areas of the several watersheds for the full 50-year period.

The data for stations marked "near," where derived partly from those at near-by points or even where interpolated from the monthly or annual charts, have not been specifically indicated as interpolations, as they are considered as representing the districts with sufficient accuracy for the purpose. Interpolated data determined by the ratio method have been indicated in all cases.

*Exposure of instruments.*—In studying precipitation data with a view to determining possible changes in the amounts received over long periods of years, it is essential that uniformity shall exist in all the details covering the final catch, including pattern of measuring gage, identical exposure throughout the period, and such factors as elevation above ground and character of surroundings, any material variations in which may seriously impair the value of the record.

Fortunately the gages used have been approximately uniform in pattern throughout the period, but their exposure has been far from ideal and has varied greatly at many of the stations. This is particularly the case with the important telegraphic-reporting stations of the bureau where local business conditions have required many changes in the locations of the gages, chiefly resulting in higher elevations, in efforts to escape the serious effects on the catch by the constantly increasing heights of near-by buildings.

At subordinate or cooperative stations, conditions usually have been more uniform, these having mostly ground exposures, but frequent changes have been necessary in the locations of the gages, due to changes in observers. However, with the large number of stations these disturbing factors tend to a counterbalancing of effects, and the final averages probably closely approximate the actual precipitation for the respective localities.

## FACTORS INFLUENCING THE AMOUNT AND DISTRIBUTION OF PRECIPITATION IN THE GREAT LAKES REGION

*Effect of water surfaces on precipitation over adjacent land areas.*—There has been much discussion concerning the effects of near-by large bodies of water on local climate. It is known, of course, that the presence of water tends to equalize local temperatures, the effects being largely in proportion to the size of the water area and its location with regard to prevailing winds, proximity to mountains, etc. In the case of precipitation, however, the relations are more obscure and in order to determine as far as possible the facts for the near-by land as well as over the water surfaces of the Lake region, Figure 1 has been prepared. This chart is based on a period of 10 years only, 1915 to 1924, inclusive, but has been prepared from the record for every station in the region having observations for those years. As these stations are mostly cooperative they practically all have ground exposures for their gages and present a group of mainly homogeneous data observed under conditions that should show with much accuracy the variations in precipitation due to local topography, proximity to bodies of water, etc.

The figures showing these averages for the 10-year period, together with the elevations of the stations above sea level, have been entered on the chart for convenience in studying the variations due to local environment.

Considering the *Michigan-Huron area* alone, ideally located in the main storm track of the country, and moderately free from important elevations to affect the free movement of the winds, it offers an excellent opportunity to determine closely the influence of water bodies and moderate elevations on precipitation.

From the data for the two sides of Lake Michigan between latitudes 42° and 45° north, we are enabled to outline three nearly equal areas on opposite shores of the lake having about equal numbers of stations and apparently almost identical elevations and surroundings. The average annual precipitation, for the 10-year period, of the three areas from north to south on the western shore are 31.2, 31.5, and 32.2 inches, respectively, while on the eastern shore in the same order they are 31.6, 31.8, and 32.7, amounts larger by 0.4, 0.3, and 0.5 inch, respectively. These differences in the annual amounts are so slight that it is apparent the interposition of this body of water has but little effect on the distribution of annual precipitation on the opposite shores; though there is a slight tendency

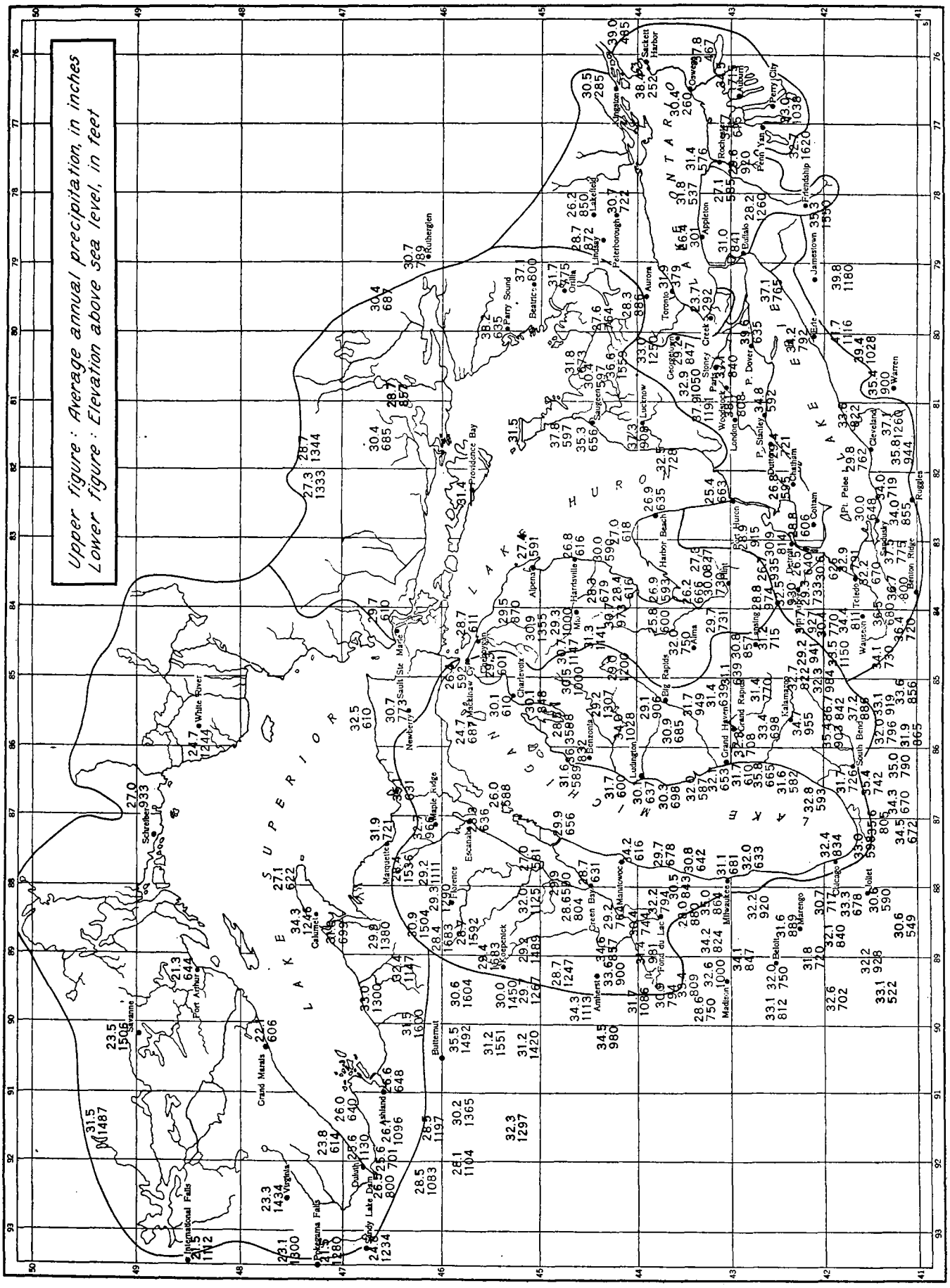


FIG. 1.—Average annual precipitation over the Great Lakes drainage basins, 1915–1924, and elevations of stations

toward more days with thunderstorms on the western side of the lake than on the eastern; on the other hand, there is evidence of more days with snow on the eastern side of the lake than on the western. Both these variations are to be expected, but they are small at the most and do not appreciably affect the annual amounts. There is, however, indication of increase on the eastern side due to the higher elevations, which would also be expected. Comparing all stations having elevations 800 feet or more above sea level, with those less elevated, an average difference is found of about 1.5 inches annually in favor of the higher altitudes.

On the respective eastern and western sides of Lake Huron, there are rather important contrasts, whether due partially to the presence of the lake, or principally to elevation is uncertain. On the Michigan side there is a descent of 300 to 600 feet from the interior of the Michigan peninsula, with elevations from 900 to 1,200 feet or slightly more, to the lake level. In this descent there is a falling off in average annual precipitation of slightly more than 3 inches, a group of well-distributed stations in the higher interior giving 30.7 inches annual precipitation, while an equally well-distributed group near the lake shore, with elevations 300 to 600 feet lower, gives an average of only 27.6 inches. This decrease of about 10 per cent can be safely assumed to be due to change in elevation, since precipitation on the lee side of elevations is usually less than that on the windward side. Furthermore the decrease is twice as much as the increase due to elevation on the Lake Michigan side of the peninsula, which, too, is in accord with conditions usually found on windward versus leeward slopes.

On the Canadian side of Lake Huron there is a sharp increase in the amount of annual precipitation and a decided change in the proportions occurring in the warmer and colder periods of the year, respectively. In this connection it might be stated that the region has frequent snowfall, though the total amounts of snow (unmelted) are usually not large.

In connection with this increase it may be noted that the Canadian weather service considers in all cases that the ratio of unmelted to melted snowfall is 10 to 1. On the other hand, the United States Weather Bureau has adopted the policy of measuring the actual amount of water from the melted snow whenever this is possible. On account of the light and dry character of the snowfall in this region and the fact that the individual snows are usually only a few inches in depth, and therefore too light to cause material compression of the lower layers, the resulting water is probably on the average materially less than the adopted ratio of 10 to 1. In view of this it is safe to assume that the amounts resulting from the two methods of obtaining the water equivalent of the snow are not strictly comparable; the effect of the presence of this lake as a disturbing factor in the distribution of precipitation is therefore rendered uncertain, although the uncertainty is not large in any event.

For the *southern watershed of the Lake Erie basin* there is strong evidence that the precipitation over the higher elevations is considerably greater than at the lower elevations near the lake. Stations along the southern rim of this basin have average annual falls of slightly more than 38 inches, while an average of those near the southern shore of the lake gives slightly less than 33 inches. Like conditions are noted locally in the other lake areas; hence it seems safe to state that where the lakes are materially depressed below the surrounding lands there will be found a considerable falling off in the precipitation over the near-by water surface as compared with that of the higher land.

In the case of *Lake Michigan* the western and southern drainage areas are not materially above the level of the lake; hence there is little change in the amounts of precipitation with approach thereto. Furthermore the principal rain-bearing winds over this lake, particularly over its southern portion, are mainly from southerly directions and hence blow up the lake rather than across, thus largely counteracting, or at least modifying, any tendency to appreciable variation in amounts of precipitation over the lake as compared with the shores.

*Possibilities of variation in precipitation due to human agencies.*—Much study has been applied to this question without definite conclusions, mainly due to insufficient length of record and uncertainty as to the comparability of existing records. However, it is the general scientific opinion that climate has not *permanently* changed within recorded history. There is evidence that local weather changes of small import may result from human agencies, such as the destruction of the forest cover, particularly of the evergreen type, which before removal must have afforded some protection from cold by diminishing the wind force, whereas removal permits freer air circulation and possibly a somewhat wider extension of windy areas.

The drainage of swamps and shallow lakes favors a rapid run-off of precipitation and lessens the moderation of temperature afforded by water surfaces. Likewise the partial disappearance of the surface vegetal cover, resulting from improper methods of agriculture or otherwise, permits both rapid run-off and greater opportunities for evaporation and radiation. None of these, however, can be judged actually to influence in any important degree the precipitation in the Great Lakes region. for the reason that the greater part of the evaporation of moisture into the air occurs over the great ocean areas far removed from the regions where it is precipitated, and that this moisture must return to earth in due course through the agency of clouds floating far above the land, unaffected by forest cover, drainage of swamps, or bareness of soil.

Much of the original forest cover of this region has been removed and doubtless there is some chance for increased wind movement and therefore increased evaporation of soil moisture, but it must be borne in mind that over forested areas a very perceptible portion of the precipitation never reaches the ground, particularly in the pine forests where much snow, or rain to a somewhat less degree, is held by the foliage, and finally lost entirely to the soil by direct evaporation, whereas when the forest cover is removed all precipitation reaches the gound, thus compensating in a measure, or even fully, for any increased evaporation of soil moisture due to higher wind movement.

While, as stated above, the forests have been largely cut, it should be remembered that this had been done many years before the recent lowering of the lake levels. Moreover, there is nearly always underbrush sufficient to perform the major functions of the forest in protecting the soil cover, retarding evaporation, etc. On the whole, therefore, the influence of the forest area, whether cut or otherwise, can be no important factor in affecting the amount of precipitation that may actually reach the soil. The effect of the removal of forests on stream flow in Wisconsin has been investigated by Prof. D. W. Mead, (*1*), who concludes that if there are any changes in the flow relations from the earlier period 1870–1890 to the later period 1890–1910, they are so small as to be immaterial.

As a check upon the possible change in precipitation due to deforestation, drainage of swamps, lakes, etc., the records of several points in or near the Great Lakes area covering the longest periods available, may be cited. (See fig. 2.)

At St. Paul, Minn., the precipitation record covers 88 years, 1837 to 1924, inclusive. This station, while probably not in the area originally forested, is close to it, and in a region where much drainage of swamps and lakes has occurred within the last half century. The average annual precipitation for the first 44 years was 27.26 inches, while the last 44 years, during which practically all the drainage and deforestation have occurred, show an annual average of 27.38, or a trifle more than when the original conditions existed.

At Marietta, Ohio, there are practically complete records of precipitation for 100 years, 1826 to 1925, inclusive. This locality, heavily forested at the beginning of the record, has been largely denuded. Here the average annual precipitation for the first 50 years was 42.35 inches, while during the last 50 years it was 42.05. Likewise at Rochester, N. Y., a record of 96 years, 1829 to 1924, shows an average during the first 48 years of 33.42 inches, while the last 48 years shows 32.75 inches.

The records for these three points—St. Paul slightly west of the upper Lakes; Marietta, south of them but comparatively near; and Rochester at the eastern end of the chain—show conclusively that in the past 100 years there has been little change in the precipitation. The assumption that deforestation, drainage, or other human activities have influenced appreciably the amount or distribution of precipitation over the area under discussion is therefore without substantial foundation.

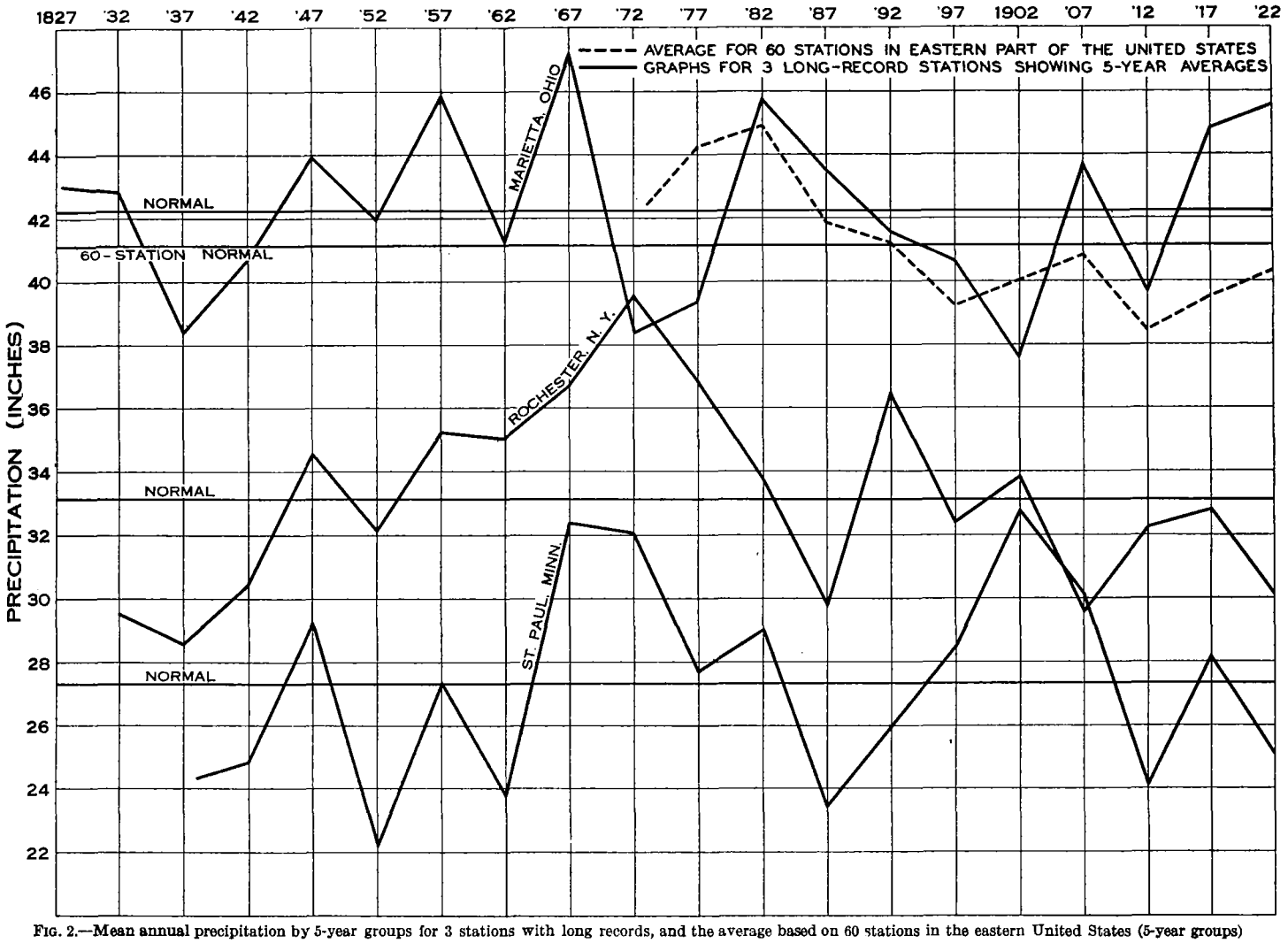


FIG. 2.—Mean annual precipitation by 5-year groups for 3 stations with long records, and the average based on 60 stations in the eastern United States (5-year groups)

## REGIONAL DISTRIBUTION OF PRECIPITATION

*Over the Great Lakes drainage basins.*—For convenience in studying the distribution over the individual lake drainage areas, the stations selected have been arranged in alphabetical order and progressively by States around each lake, thus bringing all the data applying to each lake into separate tables, with a summation into a single table showing the average precipitation for each year for the entire drainage area (See tables 2–6 at end of paper.)

The Great Lakes are located on the main highway of storms having their origin in the northwest, west, or southwest, and moving eastward toward New England and the St. Lawrence Valley. In general they have more days with precipitation than any other portion of the country, save a small area along the coasts of Oregon and Washington, the number of days with precipitation ranging from about 100 over the western drainage of Lake Superior to nearly 175 over portions of the Ontario basin.

Precipitation from individual storms in this region is rarely heavy, amounts as much as 1 inch per hour occurring on the average not more than once per year at each station, while amounts of 2 inches or more in 24 hours do not occur more frequently.

In Figure 3 is shown graphically the general distribution of annual precipitation over the Great Lakes region, based upon the 50-year averages of all the stations.

In general, precipitation increases southward from the upper to the lower Lakes, though there are well-marked exceptions, notably near the shores of southern Lake Huron, on both the Michigan and Canadian sides, where the annual averages are nearly 5 inches less than further east or west and but little greater than those found in portions of the northern Superior drainage. On the other hand, in the Georgian Bay region of Ontario there is an area with distinctly heavier amounts, in some instances averaging nearly 10 inches above the figures for northern Michigan on the opposite side of Lake Huron.

Another area of apparently light precipitation is found along the north shore of Lake Ontario and at a few points on the south shore, particularly near the lake level. Elsewhere over the drainage area the annual precipitation, as stated previously, increases gradually from north to south, ranging from about 25 inches along the northern watershed of Lake Superior to nearly 40 inches over that of southern Lake Erie.

Precipitation over the Lake region is rather evenly distributed through the year, with a tendency toward heavier amounts during the warmer portions. This is particularly noticeable over the western districts, where the distribution more nearly resembles the Great Plains and upper Mississippi Valley type, *viz:* Moderately heavy precipitation in summer and usually light in winter. Here the warm-season precipitation ranges from 60 to 70 per cent of the yearly total. Farther east, however, there is some tendency toward heavier precipitation during the colder period of the year. This is most pronounced east of Lake Huron where, in the Georgian Bay district, nearly 60 per cent of the precipitation occurs in the six months October to March, inclusive.

The percentages of precipitation for the two periods, April to September and October to March, inclusive, are shown on Figure 4.

*Over the lake surfaces.*—With regard to the amount of water falling on the lake surfaces as compared with the adjacent land areas, it is of course impossible to make definite statements, though there is strong evidence that the catch in gages where exposures are comparable with the actual lake surface is less near the lake than farther away from it.

In northern Lake Michigan, a station has been maintained at St. James on the extreme northern part of Beaver Island, located about 25 miles off the eastern shore, and approximately 50 miles from the western shore, for a period of about 20 years. Comparing identical years with Mackinaw City, on the adjacent mainland, it is found that St. James receives only 94 per cent as great precipitation as Mackinaw. Similarly, near the western shore of the same lake, on Plum Island, off the extreme northern end of the peninsula which separates Green Bay from the lake, a station has been in operation for a number of years. Comparing identical years with two stations on the mainland some 25 miles equi-distant northwest and southwest of Plum Island, it appears to receive only 92 and 96 per cent, respectively, of the amounts for the two shore stations, or 94 per cent of an average for the two stations, the same as in the preceding case.

On the southern side of Lake Superior the Keweenaw Peninsula just northeastward nearly 50 miles into the lake, at the extreme northern part of which is the station of Eagle Harbor, Mich. The gage at this station is located only a few feet above the lake on the immediate shore and exposed to the full force of the lake winds. At Calumet, about half way between the base and the extreme northern point of the peninsula, but located inland about 4 miles, there is a station also with ground exposure for the gage, but at an elevation more than 600 feet higher than at Eagle Harbor, and probably protected from the full force of the winds by the general forest cover. Comparing similar years of record, Eagle Harbor receives only 80 per cent as much precipitation as Calumet. On the other hand, comparing Eagle Harbor with Houghton, Mich., a regular Weather Bureau station at the base of the peninsula and about 10 miles inland, with the rain gage exposed on the roof of a building 57 feet high, but probably not as fully exposed to the wind as at Eagle Harbor, the catch is only 14 per cent greater than at Eagle Harbor. Houghton has 10 per cent less precipitation than Calumet, due doubtless to the difference in wind effect on the catch of the two gages, and also to the higher elevation of Calumet.

Considering the comparatively small differences in the average annual precipitation in the cases cited above, and the well-known fact that the winds are usually higher over the lake surfaces than on the adjacent shores, also that increased wind velocity materially lessens the catch, it may be expected that gages located away from the mainland, on islands or peninsulas, will register less precipitation than would be measured on the shore; but this, it is thought, would in no important particular indicate a lessened actual fall over the lake surface as a whole, as compared with the amounts received at shore stations near the lake level, but simply a lessened catch.

## IMPORTANT VARIATIONS OF PRECIPITATION IN THE LAST 50 YEARS

*The record of nonperiodic variations.*—Aside from giving the above general survey of precipitation, the purpose of this investigation was to ascertain what important changes have occurred in the amount or distribution of precipitation over the Great Lakes drainage area during the 50-year period 1875 to 1924.

Viewing the data from nearly 100 different points, on the yearly totals at each station in the separate lake basins, and averages for each basin as a whole, both by figures and diagrams, it becomes apparent at once that the outstanding features are the heavy precipitation during the first 10 years of the period over the greater part of the area, the persistent and important decreases during the following few years, the rather steady, but, on the whole, diminishing annual totals for the period about 1896 to 1916, and the marked decreases in practically all the region since 1916, including 1925.

The heavy precipitation occurring in the early years is not peculiar to the lake region alone, as is shown by figure 2.

This gives the average precipitation for five-year periods from 1872 to 1924, inclusive, over the eastern two-thirds of the United States, based upon the records of 60 well distributed observation points in that area.

For a period of about 10 years, 1875 to 1885, the precipitation for this area averaged nearly 45 inches, whereas during the remainder of the period the averages are mainly only slightly more than 40 inches or even less.